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**October 22, 2003**

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**APPLICATION NUMBER:** *60/407,723*
**FILING DATE:** *September 03, 2002*
**RELATED PCT APPLICATION NUMBER:** *PCT/US03/27605*

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JC769 U.S. PTO 09/03/02

Attorney Docket No. 00820-01

# U.S. DEPARTMENT OF COMMERCE
# PATENT AND TRADEMARK OFFICE

JC979 U.S. PTO 60/407123 09/03/02

## PROVISIONAL APPLICATION FOR PATENT COVER SHEET

Certificate Under 37 CFR 1.10
Date of Deposit: September 3, 2002
I hereby certify that this correspondence is being deposited with the United States Postal Service as "Express Mail" service under 37 CFR 1.10 on the date indicated above addressed to Box Provisional Application, Assistant Commissioner for Patents, Washington, DC 20231.

Sue Ann Carr
Express Mail No. EU 242201321 US

Address to: Box Provisional Application
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This is a request for filing a Provisional Application for Patent under 37 CFR 1.53(c)

Inventor(s) and Residence(s) (city and either state or foreign country):

| Last Name | First Name | Middle Initial | City | State or Country |
|---|---|---|---|---|
| Wadley | Haydn | N.G. | Keswick | Virginia |
| Terry | Matthew | M. | Charlottesville | Virginia |

For: **BLAST AND BALLISTIC PROTECTION SYSTEMS AND METHODS OF MAKING SAME**

6 Sheets of specification.
____ Sheets of drawings.

University of Virginia Patent Foundation claims small entity status as a nonprofit organization (37 CFR §1.9(e) and §1.27(d)). Therefore, please charge the Small Entity Fee of **$80** to **Deposit Account No. 50-0423.**

Please direct all communication relating to this application to:
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This invention was made by an agency of the United States Government or under a contract with an agency of the United States Government. The government has certain rights in the invention.

YES ☒ NO ☐ Grant No. ONR

Dated: September 3, 2002

Respectfully submitted,

By: _____
Robert J. Decker (Reg. No. 44,056)

# INVENTION DISCLOSURE FORM

## A. TITLE OF INVENTION

Blast and Ballistic Protection Systems and Methods of Making Same

## B. BACKGROUND

Light-weight armor concepts utilizing advanced ceramics, high strength polymer fibers, and composites provide excellent protection against projectiles but not the blast from nearby explosions. Emerging concepts utilizing metallic cellular metals sandwiched between pairs of ductile metal facesheets provide blast protection but less effective at protecting against projectiles. This invention achieves both blast and ballistic protection by integrating ceramics, high strength fibers, and composite materials into a metallic blast resistant structure. The integrated system uses all elements to reduce both threats.

## C. BRIEF SUMMARY OF INVENTION

Periodic, open-cell core structures made from ductile metals provide blast (and impact) protection. They are especially effective when used as the cores of sandwich panel structures. They work by transforming the energy of the blast into plastic deformation of the core/facesheet system. Cores include tetrahedral, pyramidal and Kagomé trusses, various woven or wire rectilinear arrays and honeycomb all bonded by transient liquid phase bonding, diffusion bonding, welding (including resistance methods) and adhesive bonding. By attaching a hard ceramic facesheet to the exterior of the structure and utilizing the interior free volume to position additional ceramic or ballistic fibers (e.g. Kevlar or Spectra fiber) it is possible to erode, fracture, and rotate an incoming projectile. The metal core aids the rotation process and increases the area of the fragment perpendicular to its propagation direction. A Kevlar or other ballistic fiber fabric or composite then catches the fragment and stops its penetration through the structure. Additional fragment catching fabrics/composites can be attached to the rearmost face of the structure to provide greater protection.

## D. BRIEF SUMMARY OF THE DRAWINGS

Figures One thru Four show various concepts for providing both blast and ballistic protection.
Combinations/permutations of these ideas are obviously possible. The concept involves utilizing a metallic cellular metal core with strongly bonded facesheets to absorb (by plasticity) the blast energy. Projectiles are arrested by fracture/erosion during impact with a ceramic material placed on the outer surface or the interior of the core or both. The cellular core induces projectile rotation so that a large area is presented for "capture" by a ballistic fabric. This fabric can be placed in the core or attached to the back surface of the sandwich panel. The fabric or ceramic can be incorporated in a matrix (e.g. a polymer) to create a composite attached to the faces or impregnated within the core.
The core can be any cellular metal. We envision periodic core systems for the highest performance applications. Examples are tetrahedral, pyramidal, and Kagomé trusses, honeycomb, metal textiles or cores made from rectilinear arrays of solid or hollow tubes. Inventions by Wadley and his colleagues (Sypeck, Quehellialt, and Ervin) teach how such structures can be made and identify material systems of interest. Lower performance systems could use stochastic metal foams (e.g. Duocell or Cymat foams) or non-metals.
The ceramics could be ultra-hard, high density boron carbide, silicone carbide, or aluminum oxide. Various composites utilizing ceramic, metal, or polymer matrices can also be envisioned.

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E. DETAILED DESCRIPTION OF THE INVENTION

The protection system described above can be manufactured by a variety of methods. In one approach the metallic structure is made by the methods taught by Wadley and colleagues. The ceramic front sheet is attached by metal to ceramic bonding methods. The ceramic can be added to the structure as small tiles with/without overlapping edges to accommodate thermal expansion mismatch. The ceramics can also be attached by many other approaches including adhesive bonding and mechanical attachment (bolts, rivets, etc.). Ceramics can be incorporated in the cellular structure by slurry and dry powder infiltration methods. Adhesives or brazes can, if desired, be used to bond the ceramic to the metallic structure. All or just a part of the core can be filled with this material. Whereas one cellular metal core system is ideal for retaining ceramic particles and another for blast mitigation, multiple core systems can be used such that one of the aforementioned is stacked upon another.
Ballistic fabrics can be inserted into completed periodic, open-cell core structures because of the existence of straight, continuous channels along which fibers/fiber bows of pieces of woven tape can be inserted. When low temperature metal bonding is used to make the core (e.g. resistance welding) the ballistic fabric can be inserted in the core before or as it is constructed.
The fabric or fabric composite backing layer can be attached by adhesive or mechanical methods. Numerous mechanical attachment approaches can be envisioned.

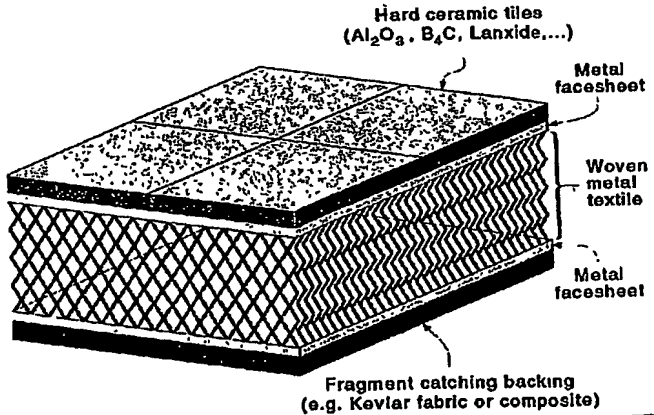



Figure 1: A simple blast/ballistic protection concept using a woven metal textile core of diamond topology. A hard ceramic front face and a fragment catching backing are added to provide ballistic protection.

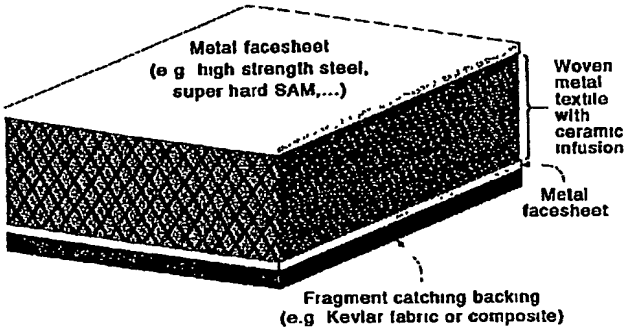



Figure 2: A more advanced integrated concept. The ceramic is place inside the open cellular metal core, reducing the overall thickness of the structure.

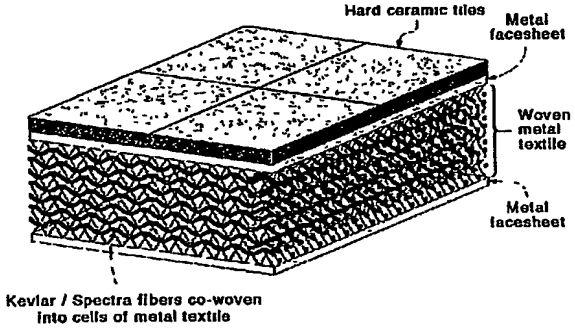



Figure 3: A blast/ballistic protection concept where the fragment catching fibers are interwoven with the metal core.

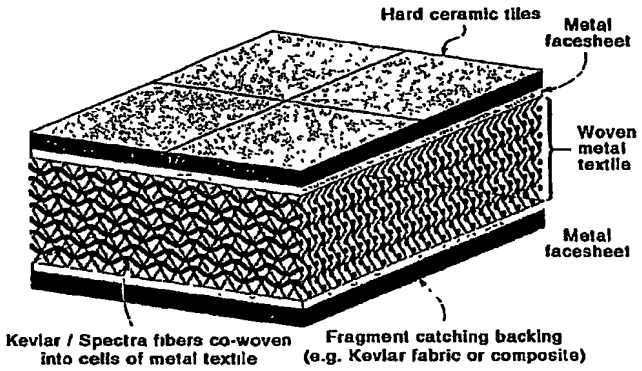
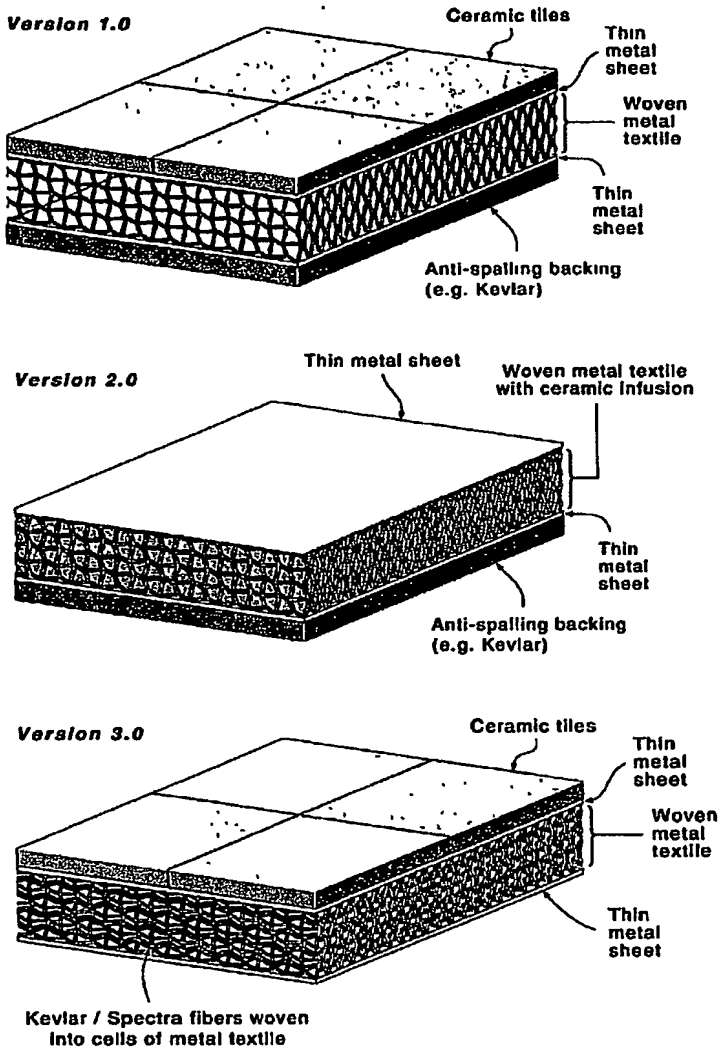



Figure 4: A highly protective system where fragment catching is performed in the core and at the rear surface. Ceramic powder could also be incorporated in all or a part of the diamond core to provide additional projectile erosion.

Alternative embodiment sketches provided by the inventors, provided below:



## Executive Summary

Open-cell, periodic cellular metals have been shown to absorb large quantities of kinetic energy when impacted, making them ideal for blast resistant armor. By combining these structures with traditional ballistic materials (ceramics and fiber reinforced composites), one can create an armor that is both blast and ballistic resistant. Beyond the advantage of a two-in-one system, the combined structure is possibly lighter than armors that provide solely blast protection. Further, the system has the potential to more effectively defeat multiple hits than conventional ballistic armor.

**References:**

The following PCT International Applications are hereby incorporated by reference herein in their entirety:

- co-pending and co-assigned PCT International Application No. PCT/US01/17363, entitled "Multifunctional Periodic Cellular Solids And The Method Of Making Thereof," filed on May 29, 2001, of which is hereby incorporated by reference herein in its entirety
- co-pending and co-assigned PCT International Application No. PCT/US02/17942, entitled "Multifunctional Periodic Cellular Solids And The Method Of Making Thereof," filed on June 6, 2002, of which is hereby incorporated by reference herein in its entirety